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Competition Between Sitka Alder and Lodgepole Pine in the Montane Spruce Zone in the Southern Interior of British Columbia

by
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EXECUTIVE SUMMARY

Competitive interactions between lodgepole pine and plant species in Sitka alder-dominated shrub communities were examined in two studies in the Montane Spruce zone. The first study examined the mean response of 3-year-old planted seedlings to manipulated densities and proximities of Sitka alder. The abundance of Sitka alder and understory plants was systematically varied, and the performance of pine seedlings and the changes in environmental resources and conditions were evaluated. The second study retrospectively examined competitive interactions among 6- to 10-year-old naturally regenerated lodgepole pine saplings and Sitka alder using a neighborhood approach.

In the first study, survival of lodgepole pine seedlings was 84% after three growing seasons. Because survival was so good regardless of levels of competing vegetation, relatively little would be gained from the added cost of vegetation control to decrease mortality rates. Seedling growth, in contrast, was clearly inhibited by increasing levels of competing vegetation. After three growing seasons, mean diameter of seedlings growing free of competing vegetation was 21% greater than that of seedlings growing under maximum vegetation density. The increases in growth resulted not from removal of alder alone, but rather from removal of alder *and* herbs. Alder and herb removal favored seedling growth by increasing soil temperature, air temperature, and light availability.

In the retrospective study, Sitka alder had a significant competitive effect on 6- to 10-year-old pine. Pine diameter growth was depressed when alder cover values exceeded between 10 and 35%, depending on the site. Below that threshold pines may actually have benefited by some alder cover, perhaps because of nitrogen fixation.

Based on the results of this study, recommendations for treating current and backlog sites are made.

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1 INTRODUCTION

Successful conifer regeneration in British Columbia requires an understanding of how biotic and abiotic factors influence seedling performance. Although the rehabilitation of unsuccessfully regenerated land appears to require that competing vegetation be reduced, little is known about the interactions among planted seedlings, competing vegetation, and the physical environment. To justify the use of competition release treatments, foresters must therefore develop an understanding of the interspecific competitive effects of vegetation on conifer seedlings.

Lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) is an important commercial tree species in the interior of British Columbia. Even-aged stands of seral lodgepole pine cover extensive areas in the Montane Spruce (MS) zone. Approximately 10 000 ha of lodgepole pine sites are harvested annually in the MS zone, of which 20–50% are expected to require vegetation management. The problem is expected to increase as lodgepole pine constitutes an increasingly larger proportion of the allowable annual cut.

Sitka alder (*Alnus viridis* ssp. *sinuata*) is a common component in the understory of lodgepole pine stands, and a well-developed Sitka alder-dominated shrub community is usually left intact following harvest. Although Sitka alder is moderately shade tolerant (Krajina *et al.* 1982), it thrives in full sunlight and rapidly increases in cover soon after harvest (Haeussler and Coates 1986). It has been recognized as a potential competitor to forest crop trees in British Columbia (Conard 1984).

Sitka alder efficiently fixes nitrogen at rates ranging from 20 to 62 kg/ha per year (Crocker and Major 1955; Mitchell 1968; Ugolini 1968; Dalton and Naylor 1975; Binkley 1982a, 1982b). Thus, it might benefit conifers by increasing the nitrogen capital of forest soils (Binkley 1982a, 1982b; Harrington and Deal 1982), although it might also suppress them by competing for moisture, light or nutrients. No studies have specifically examined competitive interactions between Sitka alder and lodgepole pine, but there is considerable evidence that other vegetation communities have a negative effect on the growth and survival of lodgepole pine (McMinn 1974; Clark and McLean 1975, 1979; Lotan and Perry 1977; McDonald *et al.* 1983; Beurmeyer 1984; Cannell *et al.* 1984; Corns and Pluth 1984).

One way that competing vegetation can hinder pine performance is by modifying environmental conditions (e.g., temperature) and aggravating resource limitations (e.g., water, light, and nutrients). The effects of competition are shown by the physiological response of pine individuals to the resources and conditions of their microenvironment (Radosevich and Osteryoung 1987). To understand the mechanisms underlying competitive interactions between lodgepole pine and the Sitka alder-dominated shrub community, we must therefore first identify limiting environmental conditions and resources and plant responses to them. In sub-boreal forests of the interior of British Columbia, for example, the performance of lodgepole pine seedlings is affected by soil temperature and the availability of light (Coates 1987), moisture and nutrients (Vyse and Navratil 1985).

Two studies were undertaken to investigate competitive interactions among lodgepole pine and plant species in Sitka alder-dominated shrub communities. The first study examined the response of three-year-old planted seedlings to different densities and proximities of Sitka alder. The abundance of Sitka alder and understory plants was systematically varied, and the survival and growth responses of the seedlings were evaluated. In addition, the availability of environmental resources and changes in environmental conditions over the range of competition levels were monitored to examine the competition processes that were occurring. Results from this first study are limited for several reasons: (1) target conifer individuals respond to local, rather than mean plant densities and proximities (Weiner 1982; Goldberg and Werner 1983); (2) third-year data may not be indicative of long-term conifer response to competition levels; and (3) competitive interactions vary from site to site depending on the levels of environmental resources and conditions.

The second study retrospectively examined competitive interactions among 6- to 10-year-old naturally regenerated lodgepole pine saplings and Sitka alder on several sites, using neighborhood techniques. The neighborhood approach overcomes some of the limitations of the competition experiment described

above. With it, the performance of a target individual is described as a function of the species, number, size, or aggregation of its neighbors (Mack and Harper 1977; Liddle *et al.* 1982; Weiner 1982,1984; Goldberg and Werner 1983). The main use of neighborhood analyses is to determine the amount of variation in the performance of target individuals that is explained by the amount or proximity of neighbors. In retrospective studies of young established conifer stands, up to 52% of the variation in conifer growth has been accounted for by competitive effects (Corns and Pluth 1984; Weiner 1984; Brand 1986a; Chan and Walstad 1987; Coates 1987; Wagner and Radosevich 1987). In this study, five Sitka alder-dominated communities were examined. Competition indices were developed and used in regression models to help explain the variation in size of the pine saplings. A competition threshold — the abundance of neighboring Sitka alder at which competition begins and pine growth is limited — was identified for each community.

There are limitations to using a retrospective approach for studying competition, and these can only be overcome by experimentally creating competition levels (Goldberg and Werner 1983; Wagner and Radosevich 1987). A natural gradient of neighboring species may have an underlying environmental cause which also affects the target species directly. For example, Sitka alder *and* lodgepole pine size may increase as moisture availability increases. An advantage to retrospective studies, however, is that preliminary models can be developed in a short period of time. The models can provide reasonable hypotheses of competitive effects that can later be tested under more controlled experimental conditions.

2 COMPETITION AMONG PLANTED PINE SEEDLINGS AND SITKA ALDER IN THE MSxk SUBZONE: THIRD YEAR RESULTS

2.1 Objectives

The objectives of this study were to examine the effects of the Sitka alder shrub community on:

1. the survival and growth of 3-year-old planted lodgepole pine seedlings, and
2. the levels of environmental resources (soil moisture, light and nitrogen) and conditions (soil and air temperature).

2.2 Methods

2.2.1 Location and site description

The study site is located in the Very Dry Cool Montane Spruce (MSxk) subzone in the southern interior of British Columbia. . It is located at 1400 m elevation about 45 km southeast of Kamloops. The site occupies a middle slope position and is of north aspect, uniform slope (25%), and uniform topography.

The original maturing seral lodgepole pine stand was harvested using grapple skidders during the summer of 1977. The site was drag scarified the same year. Today the site is dominated by a dense stand of Sitka alder and is satisfactorily restocked with naturally regenerated 10-year-old lodgepole pine. Associated herb and shrub species are pinegrass, fireweed, thimbleberry and black huckleberry.

The site is classified as zonal (MSxk/1.1). The dominant landform is morainal blanket and the lithology is grano-diorite. The soil classification is Brunisolic Gray Luvisol (Canadian Soil Survey Committee 1978). Soils are loamy, well drained, and without root-restricting layers within 60 cm. Most roots are within 40 cm of the mineral soil/humus interface. The humus is a 4-9 cm thick Orthihemimor, which is prevalent in dry boreal climates (Klinka *et al.* 1981).

The climate of the site is characterized by relatively long, cold winters and moderately short, warm summers. There is a significant growing season moisture deficit. Mitchell (1983) estimates the mean annual precipitation as 730 mm, mean snowfall as 450 cm, mean annual temperature as 3°C, and frost-free period as 70 days.

2.2.2 Experimental design and treatments

The experimental design was a randomized complete block with three replicates of each treatment. Seven treatments were randomly assigned to 17.5 x 17.5 m square plots within each block. The seven treatments represented wide ranges in density of Sitka alder (0–2514 clumps per hectare) and percent cover of herbs (0–100%) ("herbs" refers to both herbs and low-growing shrubs). Alder densities were established in June of 1987 by (1) manually cutting all clumps at the root collar and (2) controlling the amount of regrowth by selective application of 2,4-D amine. The alder treatments were characterized by the density of Sitka alder allowed to sprout. The herb treatments were established in July of 1987 by applying 2.1 kg a.i./ha glyphosate to herbs in a specified area of the treatment plots. Seedlings were covered during application. The herb treatments were characterized by the percent ground cover of herbs and low-growing shrubs remaining. Lodgepole pine natural regeneration was removed during treatment establishment.

The seven treatments applied are described in Table 1 and shown in Figure 1. Four treatments (1-4) represented a gradient in alder density and three treatments (5-7) represented a gradient in herb abundance. A plantation of lodgepole pine seedlings was established among the treatments at 2.5 m square spacing on July 4, 1987.

2.2.3 Seedling measurements

Seedling survival, condition (good, moderate, poor or dead) and growth were assessed at the end of each growing season from 1987 to 1989. Growth measurements were total height, stem diameter (measured at the root collar), and crown diameter. These were used to calculate diameter squared times height (D^2H) and height:diameter ratios. Damage cause and the condition of the tree, leader and stem were assessed concurrently with the growth measurements.

2.2.4 Environment measurements

Environmental conditions were monitored using a Campbell Scientific CR10 data logger, which was installed at a central location between treatments 1 (100% alder, 100% herbs) and 7 (0% alder, 0% herbs) in block 2. Relative humidity, air temperature and solar radiation were monitored at 1.5 m height at the central location. Precipitation amount and frequency were recorded using a tipping rain gauge attached to the data logger.

TABLE 1. Treatments applied to create gradients in Sitka alder density and herbaceous cover

Number	Name	Description
1	100% alder:100% herbs	100% of the alder was allowed to regrow (2514 clumps/ha) and the herb layer was left intact.
2	75% alder:100% herbs	75% of the alder was allowed to regrow (1886 clumps/ha) and the herb layer was left intact.
3	50% alder:100% herbs	50% of the alder was allowed to regrow (1258 clumps/ha) and the herb layer was left intact.
4	25% alder:100% herbs	25% of the alder was allowed to regrow (630 clumps/ha) and the herb layer was left intact.
5	0% alder:50% herbs	none of the alder was allowed to regrow and 50% of the herb layer was killed.
6	0% alder:100% herbs	none of the alder was allowed to regrow and the herb layer was left intact.
7	0% alder:0% herbs	none of the alder was allowed to regrow and all of the herb layer was killed.

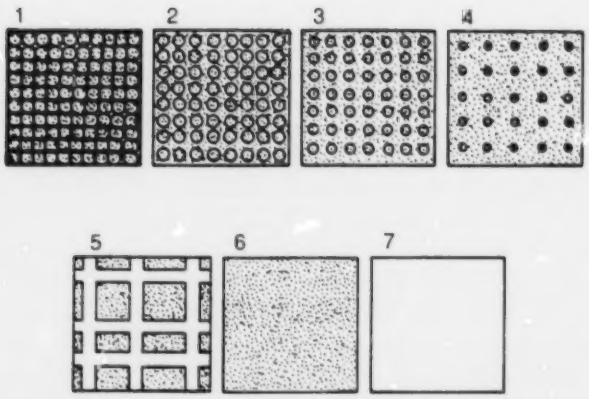

FIGURE 1. Seven treatments representing varying densities of shrubs (expressed as the % of the maximum density of 2514 clumps/ha) and the percent ground cover of herbs remaining. The treatments were: 1=100% alder:100% herbs; 2=75% alder:100% herbs; 3=50% alder:100% herbs; 4=25% alder:100% herbs; 5=0% alder:50% herbs; 6=0% alder:100% herbs; and 7=0% alder:0% herbs.

Soil and air temperature

Soil and air temperature were continuously monitored at one location in each of treatments 1 and 7 in block 2. Thermocouples attached to thermistors were located 5 and 30 cm below and 15 cm above the mineral soil surface.

Soil moisture

Soil moisture was measured in treatments 1, 6, and 7 between 1987 and 1989. During 1987, percent moisture content was estimated using gravimetric sampling. During the 1988 and 1989 growing seasons, soil water potential was measured using a Troxler 3300 Series neutron probe. Five access tubes were located in each treatment across the three blocks (total of 45 tubes). Count ratios were recorded at depths of 30, 45, 60 and 75 cm, depending on the depth of the access tube. Count ratios were calibrated to volumetric water content using gravimetric sampling and relationships between volumetric water content and soil water potential were developed using pressure-plate analysis.

Available light

Photosynthetically active radiation (PAR) available to seedlings was measured once using a Licor line quantum sensor. The measurements were made between 12:00 and 14:00 hours on a clear day in August of 1988. PAR was measured at (a) seedling terminal bud height and (b) 1 m (full sunlight) for a subset of 15 to 20 seedlings in each of treatments 1, 3, 6 and 7. The proportion of full sunlight that reached the terminal buds was calculated by dividing (a) by (b).

Soil nitrogen capital

A baseline analysis of mineral soil total and mineralizable nitrogen was done for each treatment during the fall of 1987. A second set of samples will be collected in 1992 so that the effects of varying densities of Sitka alder on soil nitrogen capital can be calculated.

Soil samples were collected from the top 15 cm of mineral soil using a standard Oakfield core. Fifteen subsamples were collected from each treatment plot. The subsamples were bulked together

to produce three composite samples per plot (21 treatment plots x 3 samples/plot = 63 samples). The composite samples were air dried and passed through a 2-mm sieve. Total nitrogen was estimated by colorimetry on semi-micro Kjeldahl digests, as described by Bremner and Mulvaney (1982). Mineralizable soil nitrogen (NH4-N and NO3-N) was estimated using the aerobic incubation technique described by Jenkinson (1968).

2.2.5 Analysis

Analysis of variance was used to test for differences between treatment means of pine performance and environment variables. The pine performance variables tested were survival and size (diameter, height, crown diameter, D^2H, and height:diameter ratio). The environment variables tested were soil water potential, available light, and total and mineralizable soil nitrogen. Treatment means were compared using the Waller and Duncan Bayes LSD procedure (Duncan 1975). Means were considered different at the 0.10 significance level.

The mean size (height, diameter, D^2H, and height:diameter ratio) of lodgepole pine seedlings in different treatment combinations was also compared in planned contrasts:

1. Is complete alder regrowth different from any reduction in alder regrowth?
   Treatment 1 vs. treatments 2,3,4,5,6,7
2. Is no alder regrowth different from partial alder regrowth?
   Treatment 5,6,7 vs. treatments 1,2,3,4
3. Is complete alder regrowth different from no alder regrowth?
   Treatment 1 vs. treatment 6
4. Is complete herb removal different from no or partial herb removal?
   Treatment 7 vs. treatments 5,6
5. Is maximum alder and herb competition different from no alder and herb competition?
   Treatment 1 vs. treatment 7
6. Is no herb removal different from complete herb removal?
   Treatment 6 vs. treatment 7

Response models of the seedling size variables (diameter, height, D^2H, and height:diameter ratio) were fit to the levels of competition represented in the treatments. Regression equations were developed which described the relationship between the dependent variables representing mean seedling growth and the independent variables: (i) density of alder and (ii) cover of herbs. The general form of two linear models fit were:

(i) diameter = $b_0 + b_1$ (alder density)

(ii) diameter = $b_0 + b_1$ (herb cover)

The general form of two quadratic models fit were:

(i) diameter = $b_0 + b_1$ (alder density) + b_2 (alder density)^2

(ii) diameter = $b_0 + b_1$ (herb cover) + b_2 (herb cover)^2

2.3 Results and Discussion

2.3.1 Sitka alder response

Sprouting of Sitka alder following manual cutting was moderately vigorous. By August of 1989 (three growing seasons following manual cutting in late June of 1987), mean height was 130 cm (maximum 160 cm) and mean crown diameter was 90 cm (maximum 180 cm). The tallest stems reached 53% of the pre-treatment height. Development of Sitka alder crowns following cutting is shown in Figure 2. Height growth rate was still constant, whereas crown diameter growth rate was declining during the third growing season.

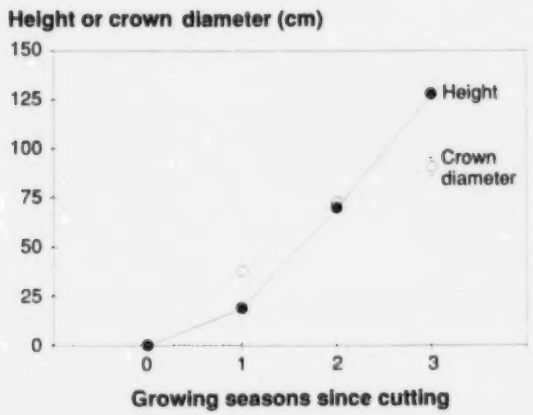

FIGURE 2. Height and crown diameter growth of Sitka alder following manual cutting.

Mean lodgepole pine height was 25 cm after two growing seasons and 45 cm after three growing seasons. Although pines were roughly equivalent to alder in height after the first growing season, they were clearly overtopped after the second and third (Figure 3). Even at maximum alder densities, however, crown closure of alder was incomplete by the fall of 1989 (30% cover at the maximum alder density).

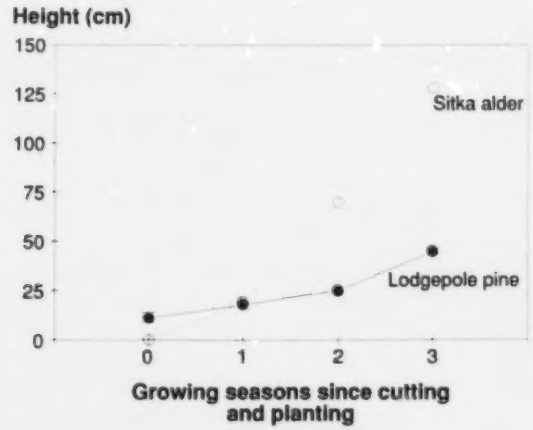

FIGURE 3. Height growth of Sitka alder and lodgepole pine seedlings following manual cutting and planting, respectively.

2.3.2 Lodgepole pine performance

Survival

Survival was stable at 84% three growing seasons after planting (Figure 4); 98% of the living seedlings were in good to moderate condition. Varying abundances of alder and associated shrubs and herbs did not significantly affect survival. Other studies have also reported pine survival to be insensitive to varying shrub canopy volumes (Lanini and Radosevich 1986; Coates 1987) and grass densities (Clark and McLean 1975). Lotan and Perry (1977), however, found that survival of lodgepole pine improved on dry sites when competing vegetation was removed and soil moisture subsequently increased.

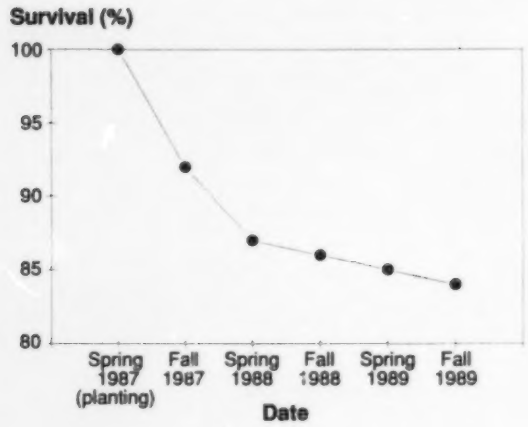

FIGURE 4. Three-year trend in survival following the planting of lodgepole pine.

Overall survival in this study was affected by drought and snowshoe hare (*Lepus* sp.) browsing. Mortality and damage due to drought occurred throughout the treatments and, although not significant, was greatest where all or part of the herbaceous layer was removed. Most of the mortality occurred in 1987, the year of treatment initiation and planting. Percent soil moisture at 10 cm depth in 1987 was greatest where alder and herbs were most abundant and least where all vegetation was removed, possibly as a result of high surface evaporation. Seedling mortality in the complete removal treatment may have been the result of low moisture availability and a high radiation load. Early mortality of lodgepole pine seedlings where moisture stress is a factor has been attributed to slow initial root elongation (Brix 1979). Brix (1979) reports that once lodgepole pine is established, however, survival and growth are favored by a sensitive stomatal control of water loss.

Browsing by hares (*Lepus* sp.) was most severe in the spring of 1988, before shrub and herb species had emerged. The greatest damage and mortality occurred in those experimental units located near high alder cover. The hares damaged 21% of the seedlings by clipping leaders or lateral shoots. Few of the browsed seedlings died and the majority formed new buds and elongated. Sullivan (1985) reports similar snowshoe hare damage to lodgepole pine plantations in many areas of central British Columbia.

Growth

Seedling growth was significantly affected by varying abundances of alder and associated shrubs and herbs after three growing seasons. Mean diameter of seedlings growing free of competing vegetation (12.0 mm) was 21% greater than that of seedlings growing among maximum alder density and herb cover (9.5 mm) (Figure 5). Planned contrasts indicate that significant increases in diameter resulted not from alder removal, but rather from the additional removal of herb and low shrub cover (Table 2). Diameter growth increased rapidly in response to decreasing herb cover (Figure 6a). Studies of other conifers consistently show positive diameter responses to vegetation removal (Lotan and Perry 1976; Clark and McLean 1978; Cole and Newton 1986; Lanini and Radosevich 1986; Coates 1987; Wagner and Radosevich 1987).

Trends in D^2H, a rough measure of stem volume, paralleled those of stem diameter. Complete herb removal significantly improved D^2H (73 cm^3) by 46% over no or partial herb removal (50 cm^3) (Table 2 and Figure 6b).

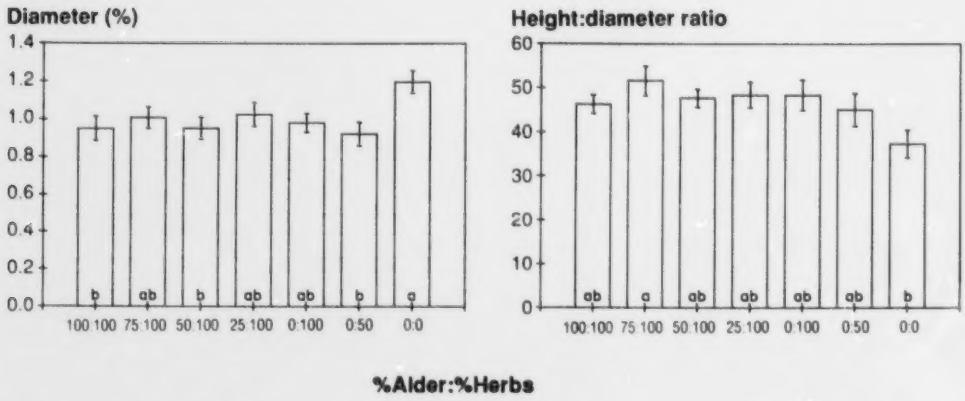

FIGURE 5. Comparison of third-year mean (i) stem diameter and (ii) height:diameter ratio among treatments. Means with different letters are different at the 0.10 significance level.

TABLE 2. Means and p-values of planned contrasts which compare lodgepole pine size among treatments. Treatments are referred to as TRT and are described in Table 1.

Contrast	Height (cm)	Diameter (mm)	Crown diam. (cm)	D^2H (cm^3)	Ht:diam ratio
Contrast 1					
TRT 1 vs 2 3 4 5 6 7:	Maximum alder growth and no herb removal vs reduced competition				
means	43.2 vs 45.3	9.5 vs 10.0	18.4 vs 20.2	46.6 vs 57.1	46.3 vs 46.4
p-value	0.16	0.36	0.29	0.27	0.98
Contrast 2					
TRT 5 6 7 vs 1 2 3 4:	No alder growth vs some alder growth				
means	43.3 vs 46.4	10.0 vs 10.0	20.0 vs 19.9	57.5 vs 54.2	43.6 vs 48.5
p-value	0.94	0.97	0.83	0.96	0.98
Contrast 3					
TRT 1 vs 6:	Maximum alder growth vs no alder regrowth (no herb removal)				
means	43.2 vs 46.2	9.5 vs 9.8	18.4 vs 19.5	46.6 vs 54.7	46.3 vs 48.4
p-value	0.13	0.73	0.61	0.32	0.66
Contrast 4					
TRT 7 vs 5 6:	Total herb removal vs no or partial herb removal (no alder growth)				
means	43.4 vs 43.3	12.0 vs 9.5	23.9 vs 18.0	73.3 vs 49.6	37.3 vs 46.7
p-value	0.95	0.01*	0.01*	0.04*	0.04*
Contrast 5					
TRT 1 vs 7:	Maximum alder growth and no herb removal vs no competition				
means	43.2 vs 43.4	9.5 vs 12.0	18.4 vs 23.9	46.6 vs 73.3	46.3 vs 37.3
p-value	0.92	0.02*	0.02*	0.04*	0.07*
Contrast 6					
TRT 6 vs 7:	No herb removal vs complete herb removal (no alder growth)				
means	46.2 vs 43.4	9.8 vs 12.0	19.5 vs 23.9	54.7 vs 73.3	48.4 vs 37.3
p-value	0.16	0.03*	0.06*	0.14	0.03*

* Significant at the 0.10 level.

Seedling morphology was significantly affected by herb density. As herb density increased, seedling height increased (Figure 6c) and stem diameter decreased. Seedling height:diameter ratio decreased from 48.4 to 37.2 when herbaceous vegetation was removed (Table 2 and Figure 5). In other words, seedlings were considerably more spindly when growing among maximum herb cover than when growing free of competition. The response model in Figure 6d shows that the largest decrease in height:diameter ratio occurred when all rather than half of the herbs were removed. Greater resource allocation to height relative to diameter growth has been observed in conifers as a response to low light intensities (Ekwebelam and Reid 1984; Waring and Schlesinger 1985; Zedaker *et al.* 1987).

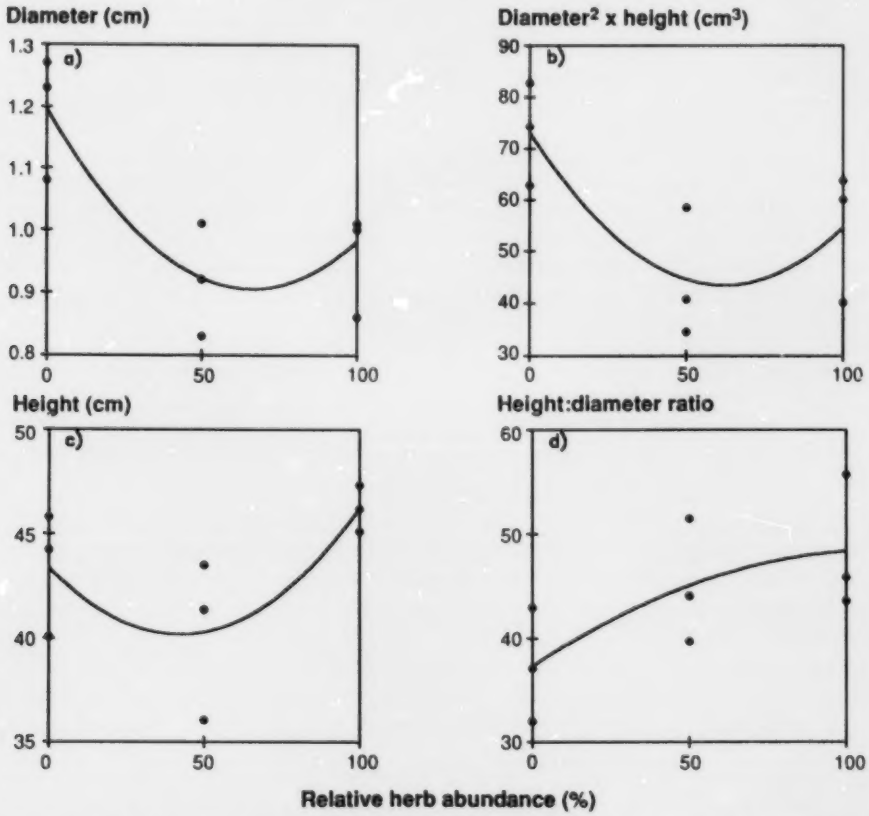

FIGURE 6. Response of lodgepole pine seedling (a) stem diameter, (b) diameter squared x height, (c) height and (d) height:diameter ratio to herb cover.

Changes in seedling morphology in response to competition can be explained by patterns in resource allocation, particularly of carbon. Lanner (1985) suggests that next to developing cones, elongating shoots are the greatest resource sink when plants are under stress. When sinks are in competition with each other and highly stressed due to competition from neighboring vegetation, not only are elongating shoots a higher priority than cambium, they also are closer to the sources of photosynthate (i.e., needles). The resultant increased height growth is advantageous because more foliage is exposed to sunlight.

Compared with low densities, competition at high densities can also result in less foliage per seedling and consequently lower photosynthetic capacity (Lanner 1985). Indeed, the crown diameter of seedlings was 33% smaller (18 cm versus 24 cm) when no rather than all vegetation was removed (Table 2). Because seedlings growing under high competitive stress have small crowns, they need

less stem tissue (i.e., diameter) for support. Decreased diameter growth, however, increases susceptibility to vegetation and snow press.

Pine height growth was a poor indicator of the effects of interference from neighboring vegetation. Many studies demonstrate that stem diameter growth is consistently more responsive to intra- and interspecific competition than is height growth (Lanner 1985; Lanini and Radosevich 1986; Coates 1987; Wagner and Radosevich 1987; Zedaker *et al.* 1987). In lodgepole pine, the annual shoot growth is fixed by the number of primordia formed in the previous year. Height growth occurs early in the growing season and the developing shoot draws largely on stored carbohydrates. Consequently, annual shoot growth is closely related to the competitive environment of the previous year. Diameter growth, on the other hand, is active through the entire growing season and hence depends on current photosynthate after stored carbohydrates have been depleted. Diameter growth is therefore more closely related to the current competitive environment.

2.3.3 Environmental effects

Competing vegetation acts directly on the environment in which seedlings grow by modifying conditions (soil and air temperature) and the availability of resources (water, light and nutrients). Stomatal activity, and hence photosynthesis, of lodgepole pine seedlings responds directly to soil moisture, air temperature, and radiation. Increasing abundances of alder and associated shrubs and herbs had a negative effect on diameter growth of lodgepole pine seedlings through a mediated effect on their microenvironment.

Soil moisture

In 1987, weather was unseasonably hot and dry before planting on July 4. However, relatively high rainfall the week after planting increased soil moisture content from 25% on July 7 to 38% on July 20.

In 1988 and 1989, soil profiles remained wetted throughout the growing season, with soil water potential never falling below -0.06 MPa at all depths and in all treatments sampled. Clearly, soil moisture availability was adequate for photosynthesis throughout the growing season. Transpiration rates in lodgepole pine start to decline when soil water potentials reach -0.1 to -0.2 MPa and are half of the maximum at -0.5 MPa. Stomatal closure occurs between -1.5 and -1.7 MPa (Lopushinsky and Klock 1974; Baer 1976). Vegetation density generally had little effect on soil moisture available to seedlings. During July and August in 1989, however, soil water potential was significantly higher where all vegetation had been removed than where shrubs or herbs remained (Figure 7).

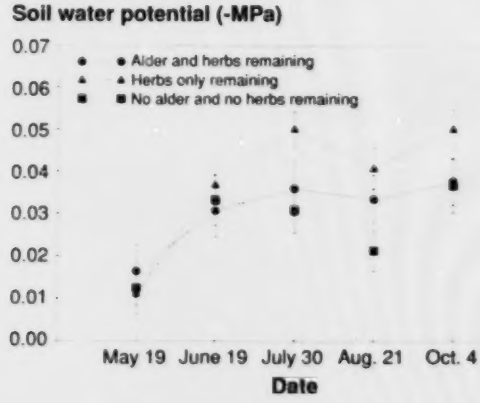

FIGURE 7. Soil water potential (-MPa) at 30 cm depth in Treatments 1 (100% alder, 100% herbs), 6 (0% alder, 100% herbs) and 7 (0% alder, 0% herbs) during the 1989 growing season. Error bars represent ± 1 standard error.

Air temperature

Air temperature at 15 cm ranged from -2 to 35°C between June 24 and October 1 in 1989 (Figure 8). Maximum air temperature was 5–10°C greater where all rather than no vegetation had been removed. Minimum air temperature varied little between treatments, lower by only 1–2°C in the complete than the no removal treatment. No frost events were recorded in either treatment after July 1.

Maximum and minimum air temperatures profoundly affect the growth and water potential of lodgepole pine (Cochran 1972; Baldwin and Barney 1976; Larcher 1983). The 5 to 10°C daytime temperature increase by removing all vegetation may have increased photosynthesis in pine seedlings.

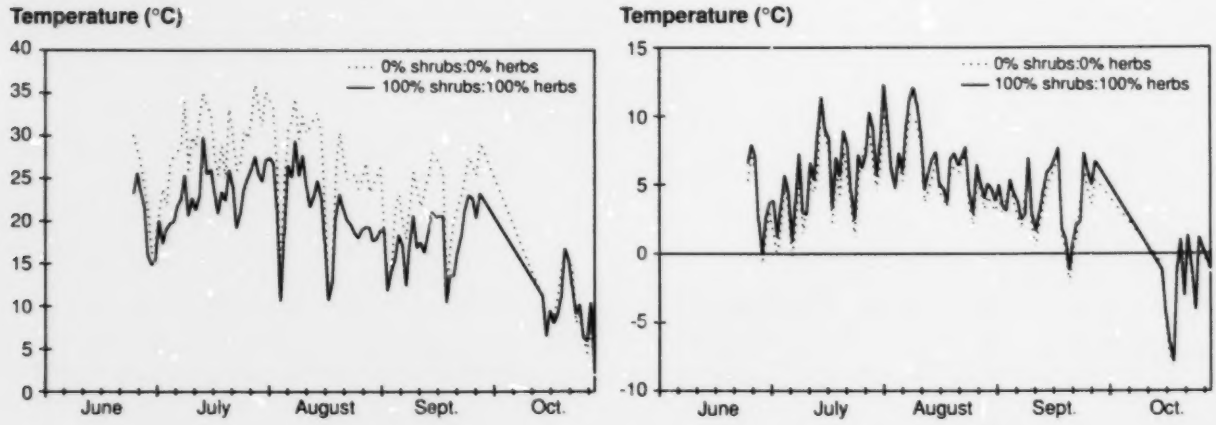

FIGURE 8. Comparison of (a) maximum and (b) minimum daily air temperatures at 15 cm height between Treatments 1 (100% alder, 100% herbs) and 7 (0% alder, 0% herbs).

Soil temperature

Daily soil temperature ranged from 6 to 21°C at 5-cm depth and 8 to 18°C at 30-cm depth between June 24 and October 1, 1989 (Figure 9). Variation in soil temperature was much greater at 5 than 30 cm. Complete vegetation removal increased maximum soil temperature by 4–8°C at 5 cm and 1–7°C at 30 cm. Minimum soil temperature increased up to 2°C at 5 cm and 4°C at 30 cm.

Soil temperatures between 2 and 5°C limit root growth in conifers (Larcher 1983). Minimum daily soil temperatures at 5 and 30 cm never fell below 6°C in either treatment during the growing season. Maximum soil temperatures occurred where all vegetation had been removed, reaching 22°C at 5 cm and 18°C at 30 cm depth in early August.

Soil temperature affects transpiration in seedlings through its effect on water uptake. Seedlings can extract water from warm soils more readily than from cold soils. Douglas-fir transpiration rates, for example, declined linearly with decreasing soil temperature and, at 1°C, declined to 19% of the rate at 20°C (Lopushinsky and Kaufmann 1984). The colder soil temperatures under the alder and herb canopy may have depressed soil water uptake.

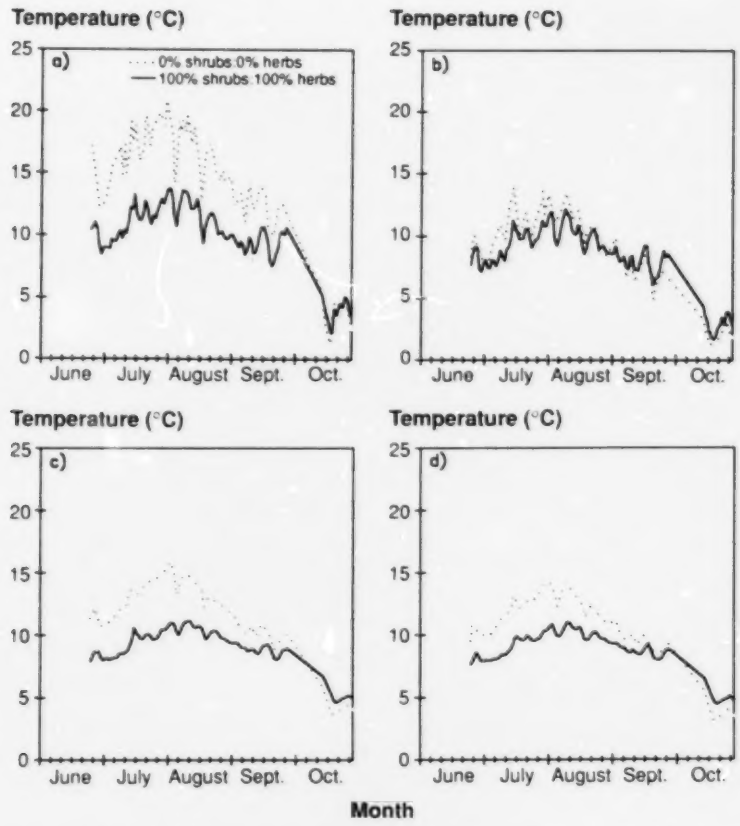

FIGURE 9. Comparison of daily soil temperature maxima at (a) 5 cm and (b) 30 cm depths and minima at (c) 5 cm and (d) 30 cm depths between Treatments 1 (100% alder, 100% herbs) and 7 (0% alder, 0% herbs).

Available light

Light available to pine seedlings was the greatest where complete alder and herb removal had occurred, but it did not significantly differ among levels of alder reduction (Figure 10). Intercepted radiation was reduced to an average of 64% of full sunlight under alder and herb canopies. Seedlings receiving the greatest amount of radiation (i.e., in the complete vegetation removal treatment) had stem diameters 21% larger than those receiving lower levels (i.e., those among varying abundances of alder and herbs). Increases in seedling growth as a result of increases in levels of radiation have been found in other studies under field (Lanini and Radosevich 1986) and nursery (Ekwebelam and Reid 1984) conditions.

Soil nitrogen capital

Total and mineralizable mineral soil nitrogen were measured in the fall of 1987 after treatment initiation. Total nitrogen (N), ammonium nitrogen (NH_4-N), and nitrate nitrogen (NO_3-N) in the top 15 cm of mineral soil averaged 1583 ±33 kg/ha, 23 ±1 kg/ha, and 5 ±1 kg/ha, respectively. Variation in total N among blocks and treatments was not a reflection of vegetation reduction treatments, since the latter were initiated only 2 months before measurement.

Typically, forms of N available for plant growth represent less than 2% of total N (Carlyle 1986). On the study site available nitrogen (ammonium nitrogen and nitrate nitrogen) in the top 15 cm of mineral soil represented only 1.7% of the amount of total nitrogen to that depth. Mineralization is likely slow here due to cool soil temperatures.

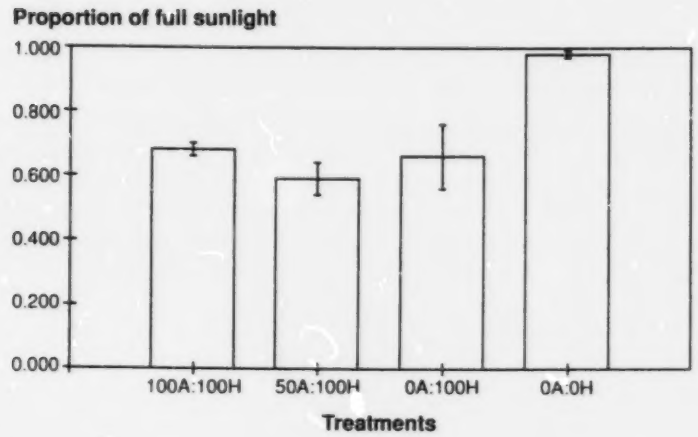

FIGURE 10. Comparison of the mean proportion of full sunlight among Treatments 1 (100% alder, 100% herbs), 3 (50% alder, 100% herbs), 6 (0% alder, 100% herbs), and 7 (0% alder, 0% herbs).

There was 127% more nitrate nitrogen where all or part of the herbaceous cover was killed than where it was left intact. Mortality of herbs may have increased the rate of mineralization by increasing soil temperature and decreasing competition between heterotrophs and mycorrhizae (Carlyle 1986). The temporary increase in nitrate nitrogen where all or part of the herbaceous cover was removed corresponded to an increase in stem diameter over treatments where the herb layer was left intact.

3 A COMPARISON OF NEIGHBORHOOD COMPETITION IN SITKA ALDER - LODGEPOLE PINE COMMUNITIES AMONG SEVERAL SITES IN THE MONTANE SPRUCE ZONE: A RETROSPECTIVE STUDY

3.1 Objectives

The objectives of the neighborhood study were:

1. to identify relationships between the size of lodgepole pine saplings and the species, amount, and proximity of immediate neighbors on a variety of sites in the MS zone, and
2. to compare sites based on the severity with which Sitka alder competes with crop trees.

3.2 Methods

3.2.1 Location and site description

The six sites selected for this study are distributed throughout the MS zone in the southern interior of British Columbia. The sites were harvested between 1977 and 1980 and today are dominated by Sitka alder and naturally regenerated lodgepole pine. Study locations were selected on the basis of species composition (predominantly Sitka alder), age (between 6 and 10 years), and hygrotope (circum-mesic).

Sites were ranked in terms of site quality, which was based on the average height of the five tallest lodgepole pines in the stand (Figure 11). Table 3 summarizes the study site characteristics.

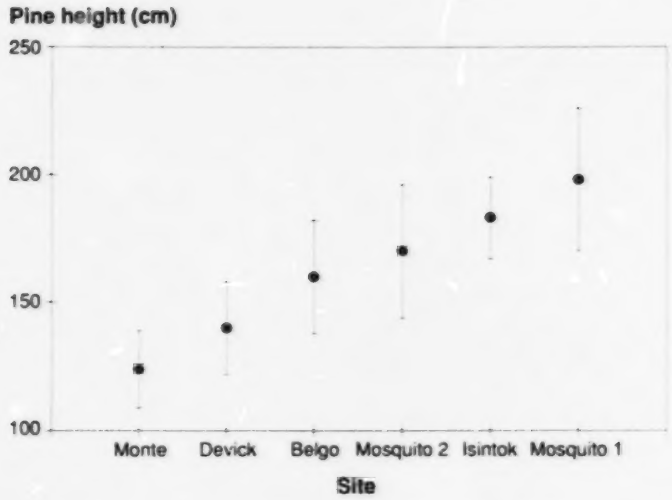

FIGURE 11. Mean height of five tallest lodgepole pines at a reference age of six on the six sites sampled.

TABLE 3. Location, biogeoclimatic classification and site characteristics of study locations

Site no.	Location	Forest unit	Variant	Ecosystem association	Hygrotope/ trophotope	Elevation (m)	Harvest year	Ave. age	Height (m)
1	Isintok Lk	Penticton	MSxk	1.1	mesic/medium	1450	1976	10	3.8
2	Monte Hills	Kamloops	MSxk	1.1	mesic/medium	1400	1977	9	2.4
3	Belgo Ck	Penticton	MSdm1	5	submesic/medium	1300	1980	6	1.5
				1	mesic/medium	1300	1980	6	1.7
				6	subhygric/medium	1300	1980	6	2.1
4	Devick Lk	Kamloops	MSdm2	1	mesic/medium	1400	1978	8	2.2
5	Mosquito Ck Site 1	Vernon	MSmm	1	mesic/medium	1500	1977	9	3.3
6	Mosquito Ck Site 2	Vernon	MSmm	1	mesic/medium	1500	1976	10	3.9

3.2.2 Sampling design

A minimum of 25 neighborhood plots were sampled within each site. Sampling occurred in June and July of 1989. The neighborhoods were defined by 10 m^2 (1.78 m radius) circular plots centered on the target pine. Sample plots were chosen to represent a wide range of competitive conditions, from low (0%) to high (100%) Sitka alder cover. Once a neighborhood of the desired alder cover was located, three to five pine saplings were selected and their neighborhood plots were measured. Only healthy, undamaged lodgepole pines were chosen. Within each neighborhood, the performance of the target pine was evaluated in relation to the species, amount, aggregation, and distance to neighbors.

3.2.3 Measurements

Neighborhood plot information that was collected included: size of the target pine; species, abundance and proximity of neighbors; and environmental conditions.

Target pine size was quantified as stem diameter, total height, relative height growth rate ((height (yr x) - height (yr x-1))/height (yr x-1)), D^2H (diameter squared x height), and height:diameter ratio.

Neighborhoods were described using both an extensive and a more detailed intensive approach (after Wagner and Radosevich 1987). In the extensive approach, the density of lodgepole pine and the percent cover of all shrubs, all herbs, and each of the dominant species were determined using the quadrant method described by Herring and Pollack (1985). In the intensive approach, each alder in the neighborhood plot was measured separately. The height, crown diameter, azimuth, and distance from the target pine to the closest crown edge of each neighboring alder were measured (Figure 12).

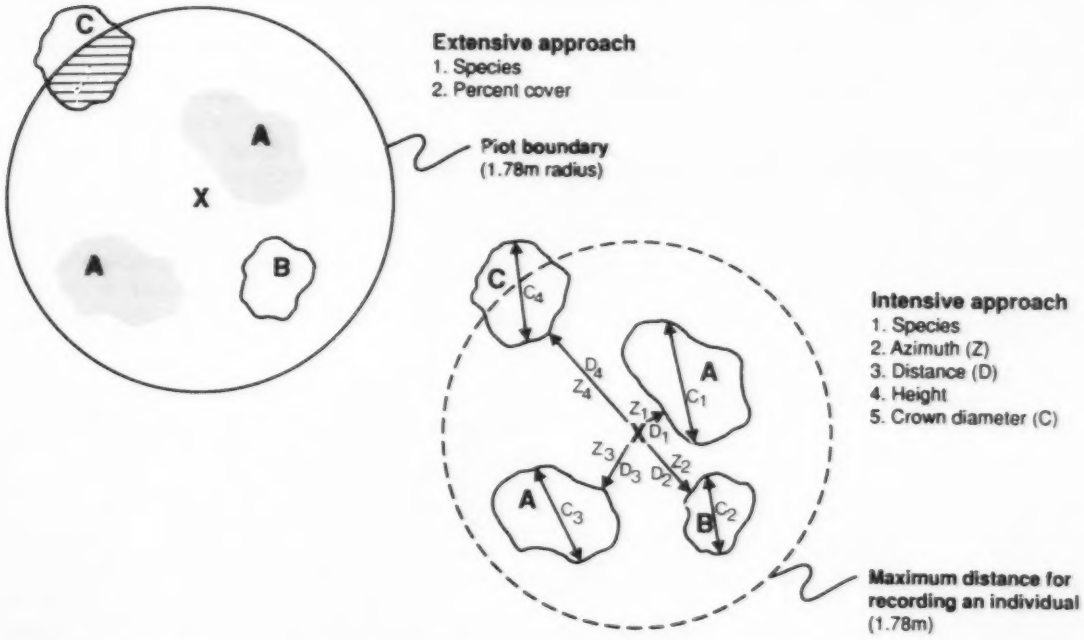

FIGURE 12. Vegetation parameters measured using the (a) extensive and (b) intensive approaches to quantifying interspecific competition (after Wagner and Radosevich 1987).

Environmental conditions recorded at each neighborhood plot included slope, aspect, organic matter depth, and hygrotope.

3.2.4 Analysis

Competition indices were calculated using extensive and intensive neighborhood measures. The indices reflect the amount of interference a target tree experienced from neighboring vegetation. Extensive indices were equivalent to the density of pine and percent cover of the dominant species in the plot (Table 4). The intensive indices were summations of vegetation parameters from all alder individuals in the plot into single values (Table 5).

TABLE 4. Extensive competition indices that were evaluated in the study

Index	Description
1	Percent cover of all shrubs
2	Percent cover of all herbs
3	Percent cover of Sitka alder
4	Percent cover of lodgepole pine
5	Density of lodgepole pine (stems/plot)
6	Percent cover of pinegrass
7	Percent cover of fireweed
8	Percent cover of lupine (Devick Lake)
9	Percent cover of grouseberry (Monte Hills, Isintok Lake, Mosquito Lake)
10	Percent cover of black huckleberry (Monte Hills, Mosquito Lake)
11	Percent cover of spirea (Monte Hills, Mosquito Lake)
12	Percent cover of thimbleberry (Belgo Creek, Devick Lake, Monte Hills)
13	Percent cover of falsebox (Belgo Creek)
14	Percent cover of prickly gooseberry (Devick Lake)
15	Percent cover of willow (Monte Hills)
16	Percent cover of twinberry (Mosquito Lake)

TABLE 5. Intensive competition indices that were evaluated in the study

Symbol	Description
Indices using 1 vegetation parameter[a]	
CAS	sum of CA
HEIGHTS	sum of HT
DISTS	sum of D
IDS	sum of inverse of D ID = 1/D
ID2S	sum of inverse of the square of D ID2 = $1/D^2$
ANGDIS	angular dispersion = $\sqrt{\frac{1 - (\cos(z_i)^2 + \sin(z_i)^2)}{n}}$
Indices using 2 vegetation parameters	
ADHS	ANGDIS * (sum of HT)
CHS	sum of CA*HT
CDS	sum of CA/D
HDS	sum of HT/D
CD2S	sum of CA/D^2
HD2S	sum of HT/D^2
ADDS	ANGDIS * (sum of D)
ADD2S	ANGDIS * (sum of D^2)
Indices using 3 vegetation parameters	
CHDS	sum of (CA * HT)/D
CHD2S	sum of (CA * HT)/D^2
ADCHS	ANGDIS * sum of (CA * HT)
ADHD2S	ANGDIS * sum of (HT/D^2)
Indices using 4 vegetation parameters	
ADCHDS	ANGDIS * (sum of (CA * HT)/D)
ADCHD2S	ANGDIS * (sum of (CA * HT)/D^2)

[a] HT = height (cm) of Sitka alder individuals within the plot,
D = distance (cm) from target lodgepole pine stem to the nearest crown edge of Sitka alder individuals within the plot,
CA = crown area = 3.1416 * (crown diameter of Sitka alder individuals/2)^2,
z_i = azimuth from the target tree to the center of alder individual i, and
n = number of individual alders within the plot

Multiple regression models were constructed to determine the relationship between pine performance (dependent variable) and competition indices (independent variables). The "best" models were selected from the combination of indices that had the highest R^2 values and included the fewest number of independent variables. A competition threshold, the Sitka alder cover at which competition began and lodgepole pine growth was limited, was identified at each site.

3.3 Results and Discussion

3.3.1 Neighborhood analyses of individual sites

Evaluation of the regression models predicting the size of lodgepole pine individuals from competition indices indicated that stem diameter was the most sensitive size measure. Stem diameter was also more responsive than height to measures of competitive interference in a preliminary neighborhood analysis of a Sitka alder/lodgepole pine community near Kamloops, B.C. (Simard 1988). The relative insensitivity of height compared to diameter growth has been commonly observed in young plantations when seedlings become spindly as a result of overtopping vegetation and the reduced light availability (Lanner 1985; Wagner and Radosevich 1987).

Extensive competition indices

Percent cover of Sitka alder was the extensive competition index best related to stem diameter on all sites. Estimates of percent cover have also proven to be of the greatest predictive value for seedling growth in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Wagner and Radosevich 1987), Engelmann spruce (*Picea engelmannii* Parry) and other lodgepole pine (Coates 1987) plantations. In this study, between 47 and 68% of the variation in pine diameter was explained by alder cover in simple linear regression models (Table 6). As the percent cover of neighboring Sitka alder increased, pine diameter decreased (Figure 13). The amount of variation accounted for by Sitka alder cover was within the range reported in other retrospective studies of interspecific competition in conifer stands (Corns and Pluth 1984; Weiner 1984; Brand 1986a; Wagner and Radosevich 1987).

TABLE 6 Linear and quadratic regression models predicting stem diameter from the extensive index, alder cover, for each of the six study sites

Variable	Site					
	Belgo Ck	Devick Lk	Monte Hills	Isintok Lk	Mosquito Lk Site 1	Mosquito Lk Site 2
Linear model						
Intercept	4.040	4.854	5.137	7.855	5.142	7.419
Alder cover	-0.040	-0.041	-0.050	-0.059	-0.049	-0.071
Model R^2	0.59	0.53	0.62	0.68	0.47	0.54
p-value	0.0001	0.0001	0.0001	0.0001	0.0011	0.0001
Quadratic model						
Intercept		4.384		6.979		
Alder cover		4.74E-4		8.39E-3		
Alder cover^2	N.S.[a]	-5.48E-4	N.S.	-7.21E-4	N.S.	N.S.
Model R^2		0.60		0.76		
p-value		0.0001		0.0001		

[a] Alder cover^2 was not a significant variable in the model at the 0.10 significance level.

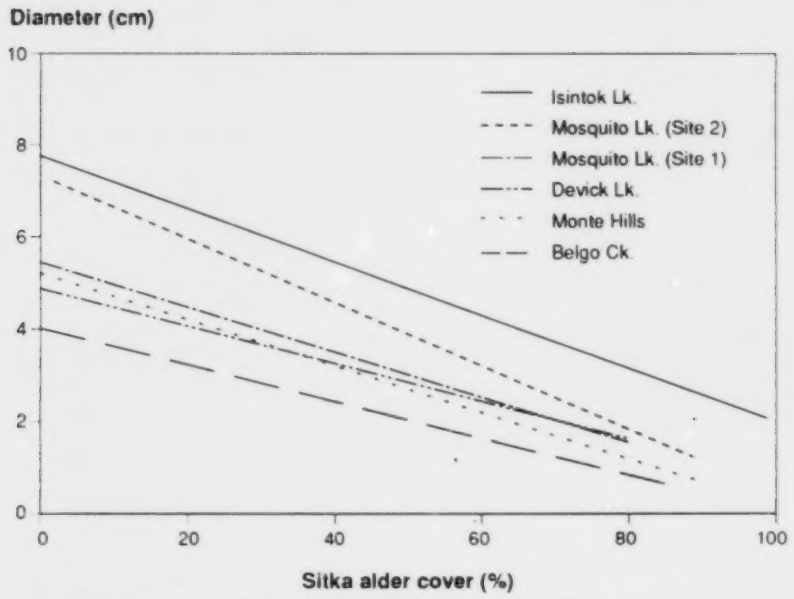

FIGURE 13. Relationship between lodgepole pine stem diameter and Sitka alder cover on the six sites sampled.

Neighborhood experiments are usually used to determine the amount of variation in target individual performance explained by neighboring species. The competitive effect of a neighbor species (Sitka alder) on a target species (lodgepole pine) is indicated by the slope of the regression of size (e.g., diameter) of target lodgepole pine on amount (e.g., percent cover) of neighboring Sitka alder (Goldberg 1983). Since the slope has a variance associated with it, the competitive effects of several neighbor species can be compared statistically and ranked in terms of the magnitude of their effects on the target lodgepole pine. From these principles, it was determined that Sitka alder had a more negative effect on pine diameter than did any of the other neighboring species. Both the absolute value of the regression coefficient (b_1) and the coefficient of determination (R^2) were larger than for any of the other species tested. Sitka alder also was the largest species in the community. Goldberg and Werner (1983) suggest that there is some degree of equivalence of per-unit competitive effect among different species since they all require the same resources (light, water, nutrients and $C0_2$) and that per-unit competitive effects are often overshadowed by size differences between individual neighbors. Larger plants, such as Sitka alder, are likely to have a greater competitive effect simply because they can take up more resources (Harper 1977).

The concept of thresholds is important to vegetation management (Radosevich and Holt 1984). The competition threshold is the weed abundance, or amount of neighbors, at which competition begins and conifer growth is limited (Cussans *et al.* 1986). When weed abundance increases above the competition threshold, environmental limitations are reached and conifer growth decreases rapidly. In this study, competition thresholds were difficult to identify due to uncontrolled site conditions. However, pine diameter appeared to decrease above alder cover values ranging between 10 and 35% (Figure 14). Pine diameter was not limited, and may actually have benefited, from a certain amount of alder cover, which varied by site. Trends in acceptable alder covers were not apparent among the six study sites.

Intensive competition indices

On all sites sampled, intensive indices explained less variation in pine performance than did the less objective extensive indices. The best single intensive index for all sites, CDS (crown area/distance), explained between 19 and 57% of the variation in pine diameter (Table 7). The predictability of the models improved only slightly with CHDS ([crown area * height]/distance), which differs from CDS only in that it includes height. On both Mosquito Creek sites, height:diameter ratio

was better predicted by intensive indices than was diameter. The CDS explained 33 and 68% of the variation in height:diameter ratio and only 19 and 44% of the variation in diameter on the two sites.

Multiple regression models which included one or more of the single parameter indices, HEIGHTS (sum of alder heights), CAS (sum of alder crown areas), DIST (sum of distances), and ANGDIS (angular dispersion of surrounding alders), are presented in Table 7. On the higher quality sites (Isintock and Mosquito lakes), multiple regression models explained more variation in pine performance than did the simple linear regression models. DIST, HEIGHTS and ANGDIS were significant (p=0.15) variables in those models. On the lower quality sites, in contrast, CDS was more predictive than the single parameter indices. Of the single parameter indices, CAS explained the most variation in pine diameter.

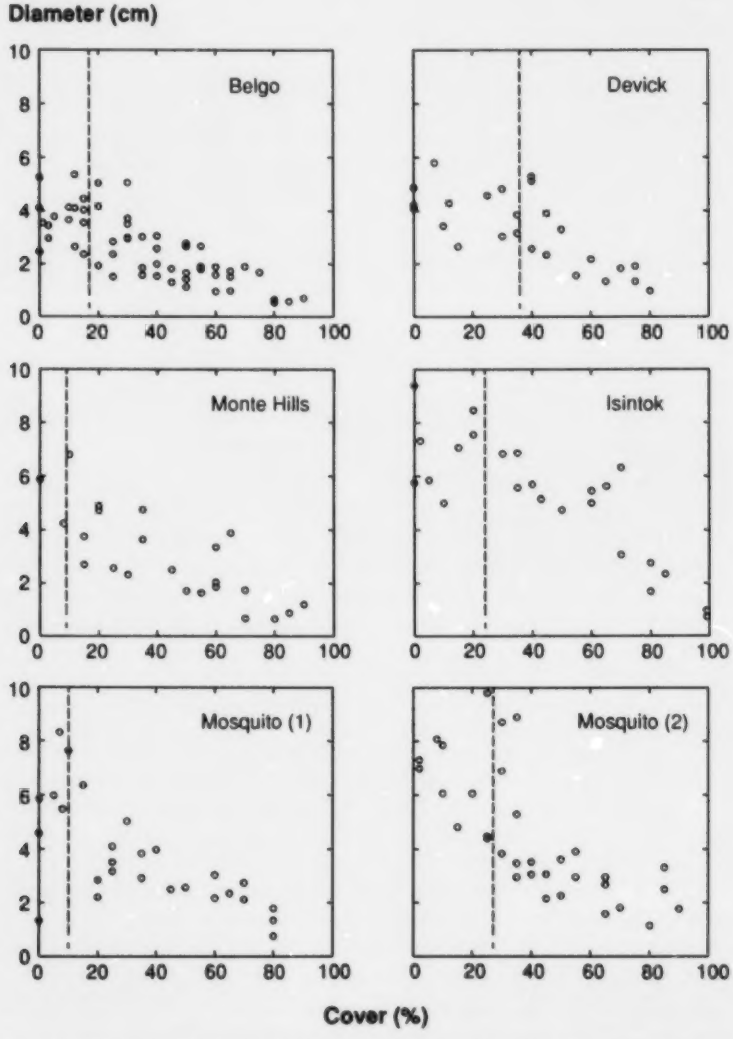

FIGURE 14. Relationship between lodgepole pine stem diameter and Sitka alder cover on the six sites sampled. Competition thresholds are indicated by a dashed line.

TABLE 7. Simple and multiple regression models predicting stem diameter from single and multiple parameter intensive competition indices for each of the six study sites

Variable	Site					
	Beigo Ck	Devick Lk	Monte Hills	Isintok Lk	Mosquito Lk Site 1	Mosquito Lk Site 2
Single parameter						
Intercept	3.739	4.431	5.034	7.338	6.625	5.988
CAS (partial R^2)	-1.88E-5 (0.46)	-1.88E-5 (0.35)	-1.73E-5 (0.44)		-1.79E-5 (0.11)	-3.33E-5 (0.09)
HEIGHTS (partial R^2)				-8.09E-3 (0.38)		
ANGDIS (partial R^2)				3.531 (0.16)	-2.911 (0.45)	
DISTS (partial R^2)				7.84E-3 (0.06)		3.03E-3 (0.36)
Model R^2	0.46	0.35	0.44	0.61	0.56	0.45
p-value	0.0001	0.0019	0.0017	0.0003	0.0001	0.0001
Double parameter						
Intercept	3.812	4.064	4.738	7.663	5.355	5.480
CDS	-2.14E-3	-1.12E-3	-3.20E-3	-2.12E-3	-1.94E-3	-9.33E-4
Model R^2	0.53	0.42	0.53	0.57	0.44	0.19
p-value	0.0001	0.0004	0.0001	0.0001	0.0002	0.0111
Triple parameter						
Intercept	3.651	4.057	4.589	7.553	5.250	5.555
CHDS	-7.54E-6	-4.06E-6	-1.26E-5	-7.03E-6	-5.75E-6	-3.43E-6
Model R^2	0.54	0.37	0.57	0.60	0.37	0.23
p-value	0.0001	0.0013	0.0001	0.0001	0.0010	0.0049

CAS is the sum of crown areas of all alders in the plot, HEIGHTS is the sum of heights, ANGDIS is the angular dispersion, DISTS is the sum of distances, CDS is the sum of crown area divided by distance, and CHDS is the sum of the product of crown area and height divided by distance.

Different measures of competition can suggest different mechanisms of competition. The intensive indices tested in regression models could help explain the processes by which Sitka alder competes with lodgepole pine saplings. For example, one-dimensional measures of competition (height of alder, distance from target pine to alder, angular dispersion of surrounding alders, etc.) can indicate competition for light (Mack and Harper 1977; Weiner 1984). Two-dimensional measures (crown area of alder, square of the distance from pine to alder, etc.), on the other hand, can indicate competition for two-dimensional space (e.g., horizontal and vertical root space). Weiner (1982, 1984) suggests that competition for two-dimensional space implies competition for soil-based resources (water and nutrients). The most predictive regression models selected for higher quality sites included HEIGHTS, DISTS and/or ANGDIS as the most important variables, suggesting that light availability may have an important effect on pine size. In contrast, the regression models selected for lower quality sites included only CAS or CDS, suggesting that competition for soil based resources (e.g., moisture) may be as important as competition for light.

3.3.2 Neighborhood analysis including all sites

Multiple regression models were developed, which included data from all six sites sampled. The dependent variables tested in the model were: slope, aspect, hygrotope, subzone (an index of climatic conditions ranging from cold and dry [0] to warm and moist [4]), organic matter depth, age of the pines, and competition index. The model for stem diameter had the highest R^2 value (0.60) and included, in descending order of importance, the following dependent variables: alder cover (partial R^2 value of 0.37), age (0.11), pinegrass cover (0.04), organic matter depth (0.04), and hygrotope (0.04) ($p=0.0001$). Note that competition indices accounted for over 40% of the total variation in the model.

4 SUMMARY AND RECOMMENDATIONS

4.1 Summary

The purpose of the two studies described in this report was to investigate competitive interactions between lodgepole pine and plant species in Sitka alder-dominated shrub communities in the Montane Spruce zone. The first study examined the mean response of 3-year-old planted seedlings to manipulated densities and proximities of Sitka alder on a single site near Kamloops, B.C. The abundance of Sitka alder and understory plants was systematically varied and the performance of pine seedlings and the changes in environmental resources and conditions were evaluated. The second study examined competitive interactions retrospectively among 6- to 10-year-old naturally regenerated lodgepole pine saplings and Sitka alder using a neighborhood approach.

Survival of lodgepole pine seedlings on the study site near Kamloops was 84% after three growing seasons. Because survival was so good regardless of levels of competing vegetation, relatively little would be gained from the added cost of vegetation control to decrease mortality rates. The principal causes of mortality were herbivory and desiccation following planting.

Seedling growth, in contrast, was clearly inhibited by increasing levels of competing vegetation after three growing seasons. Mean diameter of seedlings growing free of competing vegetation was 21% greater than that of seedlings growing under maximum vegetation density. The increases in growth resulted not from removal of alder alone, but rather from removal of alder, herbs (pinegrass and fireweed), and low-growing shrubs (thimbleberry and huckleberries). Alder and herb removal favored seedling growth by modifying environmental conditions and increasing resource availability. Most notably, soil temperature, air temperature, and light availability increased.

In the retrospective study, Sitka alder had the greatest competitive effect on 6- to 10-year-old pine, compared to the other dominant species in the community. However, Sitka alder was also the largest neighbor and of most similar size to lodgepole pine. The size difference between Sitka alder and the other neighbors likely overshadowed species differences in resource use patterns. The change in relative competitive importance from herbs at the seedling stage to alder at the sapling stage may reflect on the age and size symmetry of pines and neighboring vegetation.

The intensive indices which best predicted pine diameter on higher quality sites included the height, distance to, and angular dispersion of surrounding alders. According to Weiner (1984), these one-dimensional measures suggest that light availability has an important effect on pine size. In contrast, crown area over distance to surrounding alders was the intensive index which best predicted pine diameter on lower quality sites. This suggests that competition for soil-based resources may be as important as competition for light.

Although competition thresholds were difficult to identify among the six sites sampled, diameter appeared to decrease above alder cover values ranging between 10 and 35%. Pine diameter was not reduced and may actually have benefited by some alder cover, the amount of which depended on the site. There was no apparent trend in acceptable alder cover levels among sites. Identification of competition thresholds may have been obscured by the lack of experimental control over confounding biotic and abiotic factors.

The potential growth of pines in the MS zone is partially a function of their competitive environment, age, hygrotope, and organic matter depth. A considerable amount of variation in pine size, however, remained unexplained. Furthermore, variation among seedlings increased as competitive interference decreased. At high alder cover, competition had an important influence on pine size. At low cover, however, other factors such as genetic expression or site conditions may be more important. Goldberg (1987) suggests that competition acts as a boundary constraint on the maximum potential size of individuals rather than as an accurate predictor of actual size. Seedlings that are growing below the boundary are not necessarily unaffected by competition. However, heterogeneity in genotype, initial size, herbivory, or the microenvironment may underlie the variability of performance within similar neighbor densities. *The regression models, therefore, should not be used as accurate predictors of pine growth, but rather as means for identifying factors which are important to performance.*

4.2 Recommendations

The results are preliminary and more work is required before relationships between lodgepole pine growth and Sitka alder levels can be used to develop site-specific guidelines for vegetation reduction. In the interim, however, the following recommendations are made:

1. Large stock should be planted and, where possible, seedlings should be protected from herbivory.
2. To maximize seedling growth, the amount of competing vegetation should be minimized for a few years after planting. Removing herbs and low-growing shrubs, in addition to Sitka alder, is necessary to improve growth significantly.
3. In naturally regenerated communities, Sitka alder has a significant competitive effect on pine saplings. Many pines will remain suppressed under the alder canopy, although many also will be free to grow within 10–15 years. In general, Sitka alder cover of less than 35% will not suppress — and may actually benefit — pine performance because of alder's nitrogen-fixing ability.

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